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Strawberry Yield over Red versus Black Plastic Mulch

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ABSTRACT

Plastic mulches are frequently used in raised-bed culture of strawberry (*Fragaria* × *ananassa* Duch) to conserve water, control weeds with less herbicides, and keep fruit clean. The most commonly used plastic mulch color is black. It was hypothesized that a specially formulated red plastic mulch that reflects a higher far-red to red photon ratio could regulate photosynthate allocation enough to increase yield of strawberry. Yields over the red plastic (SRM-Red) were compared with those over standard black plastic in field experiments at a research center and on a commercial strawberry farm. Yield per plant and size per berry were greater over the red than over the black plastic at both locations. The yield advantage of red mulch relative to black occurred whether the red plastic was placed directly over the soil or over a layer of black plastic. It is concluded that strawberries were larger over the new red plastic mulch because reflected far-red and red light affected phytochrome-mediated allocation of photosynthate, and more was directed to developing fruit.

Plastic mulches over trickle irrigation systems are widely used in raised-bed culture of strawberry to conserve water, control weeds with less herbicides, and keep fruit clean. Black is the most widely used color of plastic mulch (2, 3, 10). It is well documented that black polyethylene mulched strawberry produced higher yields of high quality fruit than unmulched controls (12).

Recently developed colored mulch technology adds a growth regulatory effect of reflected wavelength combinations in the visible and far-red parts of the electromagnetic spectrum (7). The approach combines the benefits of black plastic mulch with additional growth regulatory benefits of reflected morphogenic light to improve yield and quality of field-grown plant products. An important first step toward development of colored mulch technology was the documentation that far-red light (FR) reflected from nearby plants (1, 4, 5, 9) affected the far-red to red (FR/R) photon ratio enough to act through the natural phytochrome system within a growing plant to regulate allocation of photoassimilate (5, 6, 7). This was followed by determination that plants also respond to morphogenic light that is reflected from dead plant residue on the soil surface, and this discovery led to evaluation of growth patterns of a number of shoot and root crop plants in sunlight over a wide range of colors that were painted onto panels placed on the soil surface (7). In the early experiments, growth characteristics sometimes differed among plants that were grown over the same color because two batches of a given color may reflect the same in the visible spectrum but quite differently in the FR range. That is, they could appear the same to a human but reflect a different FR/R photon ratio and affect plants differently.

On the basis of earlier controlled environment experiments (4), it was predicted that a FR/R photon ratio higher than the ratio in incoming sunlight (at the same time and place) would favor shoot crops, and a FR/R ratio lower than the ratio in incoming light would favor below ground crops. Plant response was as predicted (7). The controlled environment experiments combined with field studies of shoot crops grown over painted panels (with known reflection spectra) led to development of a specially formulated red plastic mulch that increased the yield of tomato (*Lycopersicon esculentum* Mill.) relative to yield over standard black plastic mulch (8).

Because soil temperature affects production of horticultural crops (2), that component was minimized in the tomato productivity study by taping a layer of red plastic over the standard black plastic (8). The procedure resulted in very similar soil temperatures but quite different reflection spectra. In that study, soil temperatures were recorded 10 cm below the plastic midway between plants within rows in the morning and near solar noon soon after transplant to the colored mulch plots in each of the 3 yr. Temperatures were usually less than 0.5°C warmer under the black plastic. This is explainable because black absorbs all colors of the spectrum, whereas the red layer absorbed the shorter wavelengths and reflected much of the R and FR; only wavelengths that were transmitted through the red plastic could be absorbed by the black underlayer. That experimental system allowed evaluation of yield response to reflected spectrum while minimizing soil temperature effects (8). The tomato study also indicated that the reflecting surface must be clean and large enough to reflect to the developing fruit and adjacent parts of the plant.

It was hypothesized that distance from the reflecting surface to the developing fruit should also influence effectiveness of the reflected light. If correct, a low-growing plant whose developing fruit extends beyond its leaves (over the reflecting surface) should be highly responsive to morphogenic light reflected from the red mulch surface. Strawberry plant growth and fruit development patterns fit this description. The present study was conducted to compare strawberry yield and fruit size over the new red versus the standard black plastic mulch in raised-bed culture at a research center and on a commercial strawberry farm.

MATERIALS AND METHODS

The experiments were conducted in 1995-1996 and 1996-1997 at the Coastal Plains Soil, Water, and Plant Research Center near Florence, SC, and at the Bell Strawberry Farm

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Abbreviations: FR, far-red light; FR/R, far-red to red photon ratio; R, red light; SRM, selective reflective mulch.

near Johnston, SC. These locations are about 250 km apart. All experiments were done with the cultivar Chandler. Each year, plants used at both locations were purchased at the same time from Ghesquire Farms, Inc. (Sincoe, ON). The plants were stored in darkness at 4.5°C prior to transplanting. Yields over the red plastic mulch [manufactured by Sonoco Products Co., Hartsville, SC, and marketed as Selective Reflective Mulch (SRM-Red) by Ken-Bar, Inc., Reading, MA] were compared with those over standard black plastic mulch in trickle-irrigated field plots. The same roll of red plastic was used for all of the experiments. The number and total weight of berries per plot were recorded at each harvest date. Weight per berry was calculated on a per plot basis at each harvest. Strawberry yield data were analyzed by analysis of variance (ANOVA) as outlined by SAS Institute (11). Specific details for each of the locations are described below.

Coastal Plains Research Center

Soil samples were taken and plots were fertilized according to Clemson University Cooperative Extension Service recommendations. The fertilizer was broadcast and disked into the upper 0.15 m of soil. Black polyethylene mulch (1.5 m wide), trickle irrigation tubing, and methyl bromide (bromomethane) fumigation were all applied in a single operation in mid-August each year. This operation also included raising the beds and covering the edges of the plastic with soil to keep it in place. The mulch-covered beds were 0.9 m wide and 0.15 m high. They remained undisturbed until early October when the red plastic was put in place over the fumigated beds, holes punched, and strawberry transplanted. The within-row plant spacing was 0.3 m and rows were 2 m apart. Strawberries were harvested two or three times per week depending on ripening rate. Some experimental details differed between years.

1995-1996

There were eight replicate plots, and the two colors of mulch were randomized within each of those plots. The red was taped over the existing black plastic before the holes were made. There were 10 plants per color per replicate. Soil temperatures were measured to the nearest 0.1°C 10 cm below the standard black and below the red (with black underlayer) plastic mulches at 1245 h ± 15 min on a sunny day in mid-May. There were 10 separate measurements below each color in each of three replicates.

A late freeze occurred the third week of March after the plants had begun to flower and form berries. The freeze killed most of the early flowers and berries, resulting in a delayed and very short harvest season.

1996-1997

There were 10 replicate plots, and three color treatments were randomized within each replicate. The color treatments were the standard black control, red plastic placed over a layer of black plastic, and red plastic over bare soil. The red plastic treatments were put in place a month after the black plastic and methyl bromide were applied. The red (with black underlayer) plastic was applied by taping it in place. For the red (over bare soil) treatment, the black plastic was cut out and replaced with red just before holes were punched and plants transplanted. Within-row and between-row plant spacings were the same as in the previous year. There were 10 plants per color treatment per replicate. Berries were harvested two or three times per week from 8 April until 16 May to compare yields during the peak demand for fresh strawberries. Accumulated yields per plot through three different harvest dates are presented.

Bell Strawberry Farm

Bell Strawberry Farm is a large commercial operation which includes some "pick-your-own" customers and many visitors. All field operations concerning land preparation, soil fumigation, raising beds, and laying black plastic were according to their procedures in late August each year. The test plots were in adjacent rows in a corner of a two hectare strawberry field. The black plastic remained in place over the fumigated soil until early October each year, when we marked the plots and placed the red plastic. The farm crew punched the holes by machine, and hand-set the plants after the red plastic was in place. Two rows of holes were punched in each plot. The two rows were 0.3 m apart and the plants were 0.3 m apart within each of the two rows per color panel. During harvest season we traveled from Florence to Bell Farm to pick the berries. Strawberry weights and numbers were recorded and analyzed on a per plot basis.

1995-1996

There were eight replicate plots, and the red and black plastic mulches were randomized within each plot. The red plastic was taped over the existing black. Individual color plots were 3.6 m long and contained 22 harvestable plants (berries from plants at the intersection of the two mulch colors were not included in any of the harvests). Because of the late-March freeze, early berries were lost, and berries were harvested only six times from 2 to 29 May.

1996-1997

There were eight replicate plots and two color treatments. The two mulch color treatments were randomized within each plot. Standard black plastic was compared with red plastic taped over the existing black plastic. As in the previous year, each color plot was 3.6 m long and contained 22 harvestable plants. The harvest season began on 26 March and ended on 6 May, when the market demand for fresh strawberries began to diminish. Berries were harvested two or three times per week during that period.

RESULTS AND DISCUSSION

Coastal Plains Research Center

1996

Yields were influenced by a late-March freeze that killed or severely damaged flowers and young berries. Because of the late freeze, only the fruit harvested after 14 May were evaluated. Weight of fruit harvested from 14 to 27 May averaged about 16% greater over red than over black plastic mulch and the difference was statistically significant. Comparison of the five largest berries per plot in the final harvest (27 May) of the season showed that berries developed over red mulch averaged 16.0 g while those that developed over black averaged 13.9 g and the difference was significant at $P = 0.05$.

Soil temperatures are known to influence horticultural crop production (2); however, mean soil temperature 10 cm below the black plastic was about 0.2°C higher than the temperature 10 cm below the red, as used in this study. It is not likely that the slightly higher soil temperature under the black plastic would cause berries to average about 15% smaller over the black versus those grown over red plastic. Thus, strawberry production over the SRM-Red versus standard black plastic mulch suggested a yield advantage in favor of red because of reflection from the mulch surface.

1997

Yield per plot and weight per berry developed over red plastic were greater than those over black plastic (Table 1). The yield and size of berries that developed over the two red mulch treatments did not differ statistically from each other whether the red plastic was placed directly over bare soil or over a layer of black plastic.

On a percentage basis, the increase in yield over red versus black mulch was greatest in the early part of the season. Accumulated weights per plot from 8 April to 2 May averaged 34.8 and 39.3% greater over the red (with black underlayer) and red (over bare soil), respectively, than weights over the standard black mulch. During this same period, number of fruit per plot were numerically greater over red and weight per berry averaged more than 20% greater over both red treatments than over black. It was evident that the greater yield over red was primarily due to greater size per berry and to a lesser extent to more berries per plant (Table 1). In fact, the greater size per berry over red versus black for harvests through 16 May was significant at $P = 0.01$.

A possible explanation for the greater percentage increase in size per fruit of strawberry (Table 1) as compared with the percentage increase in size per fruit of tomato (8) over red versus black might be nearness of the developing fruit to the reflecting surface. This would be consistent with seedling hypocotyl elongation response to nearness of other seedlings, which reflect FR and affect the FR/R photon ratio (1, 4, 5). Also, the measured FR/R photon ratio reflected by SRM-Red under field conditions diminishes with distance from the reflecting surface (unpublished data). Therefore, it is reasonable to expect that comparison of fruit size of strawberry and tomato would show greatest percentage increase in size per fruit for strawberry when grown over the red versus black reflectors.

Table 1. Strawberry yields accumulated during the early, intermediate, and total harvest season over standard black versus SRM-Red plastic mulch at the Coastal Plains Research Center near Florence, SC, in 1997.

Mulch color	Fruit per 10-plant plot					
	Weight		Number			
	g	(% gain)	no.	(% gain)	g/fruit†	(% gain)
Early season (8 April–2 May)						
Black (control)	1153b‡	–	70a	–	16.0b	–
Red (over black)	1554a	(34.8)§	77a	(9.7)	19.4a	(20.8)
Red (over soil)	1606a	(39.3)	81a	(15.1)	20.1a	(25.6)
(8 April–9 May)						
Black (control)	1658b	–	100a	–	16.1b	–
Red (over black)	2014a	(21.5)	103a	(3.0)	19.0a	(17.6)
Red (over soil)	2053a	(23.8)	107a	(7.2)	19.4a	(20.7)
Total season (8 April–16 May)						
Black (control)	2759b	–	164a	–	16.6b	–
Red (over black)	3286a	(19.1)	172a	(5.0)	19.0a	(14.6)
Red (over soil)	3151a	(14.2)	171a	(4.5)	18.5a	(11.3)

† Values for weight per fruit are means of the values obtained for each of the harvests.
‡ Values are means per plot for accumulated yields from 10 replicate plots of 10 plants each per color. Within each subcolumn, values followed by the same letter do not differ significantly at $P = 0.05$.
§ Percentages were calculated before numbers were rounded off.

The difference in berry size between those grown over black and red (with black underlayer) (Table 1) is not attributed to a difference in soil temperature because they were very similar, as discussed above. Also, the small numerical differences in strawberry yield over red (with black underlayer) versus red (over soil) were not statistically significant (Table 1). Therefore, the strawberry size differences over the black versus red mulches are attributed to reflection of light wavelengths that acted through the natural photomorphogenic pigments (primarily phytochrome) within the growing plant to regulate allocation of more photoassimilate to the developing fruit over the FR-reflecting red plastic than over the standard black plastic mulch.

Greater yield per plant and weight per berry over the red mulch during the April and early May harvest season coincides with the peak demand for fresh strawberries in this region. The results with strawberry at the Research Center suggest that the red plastic mulch could offer a competitive advantage for commercial growers who supply "pick-your-own" customers and/or other fresh market customers.

Bell Strawberry Farm

1996

The late-March freeze damage at Bell Farm was less severe than at the Center, and accumulated yield means per plot over the six harvests (2–29 May) are presented in Table 2. Total yield per plot and average weight per berry were significantly greater over the red mulch. The number of berries harvested were essentially the same over red and black. It must be noted, however, that on several of the harvest dates there were fresh footprints next to red-covered rows within the marked plot area.

As at the Center, average weights per berry for the five largest berries per plot on the last harvest date (29 May) were greater over the red than over the black mulch. Mean weights per berry (17.1 and 15.0 g over red and black mulch, respectively) differed significantly ($P = 0.02$) on that final harvest date.

1997

There was no freeze damage in 1997, and the harvest season was much earlier. Strawberry weight per plot and weight per berry were again significantly higher over red (with black underlayer) than over black plastic (Table 3). The number of berries harvested per plot did not differ significantly between the mulch colors.

Table 2. Strawberry yields accumulated from 2 May to 29 May over standard black versus SRM-Red plastic mulch during the freeze-delayed season at Bell Strawberry Farm near Johnston, SC, in 1996.

Mulch color	Fruit per 22-plant plot		
	g	no.	g/fruit
Black	3622†	272	13.3
Red	3981	265	15.0
Signif. (P value)	0.06	NS	0.01

† Values are means per plot for yields from eight replicate plots of 22 plants each per color. NS = not significant at $P = 0.1$.

Table 3. Strawberry yields accumulated from 26 March to 6 May over standard black versus SRM-Red plastic mulch at Bell Farm near Johnston, SC, in 1997.

Mulch color	Fruit per 22-plant plot		
	g	no.	g/fruit
Black	6801†	433	15.7
Red	7408	439	16.9
Signif. (*P* value)	0.04	NS	0.01

† Values are means per plot for yields from eight replicate plots of 22 plants each per color. NS = not significant at $P = 0.1$.

However, as in 1996, fresh footprints were found next to red mulched plots on several of the harvest dates. It is possible that some unscheduled "taste-testing" contributed to numerically fewer strawberries harvested over the red mulch. Nevertheless, the greater size per berry and yield per plot over red mulch were consistent with results obtained at the Research Center. Such early season yield response can be advantageous to both large-scale producers and home gardeners.

An informal testing of red plastic mulch placed directly over the soil provided some interesting observations. In six plots in which a legume cover crop had been completely killed, weight of berries per plot were numerically higher when the red plastic was placed on the bare soil than when placed over a layer of black plastic. This was consistent with results obtained at the Research Center (see Table 1). However, in two plots where the legume cover crop was not killed, growth below the plastic extended through the holes and crowded some of the strawberry plants. Thus, the trend observed in 1997 with strawberry at Bell Farm was that the red plastic placed directly over bare soil was superior to standard black plastic and as good as or better than red with a black underlayer; however, vigorous plant growth below the plastic was undesirable if growth extended through the holes and crowded the strawberry plants.

CONCLUSIONS

The colored mulch approach combines the soil and water conserving benefits of mulch with the growth regulatory benefits of reflected morphogenic light. Because the soil temperatures below the black and the red (with a black underlayer) plastic mulches were very similar in this study, it is concluded that strawberry yield and fruit size were responsive to morphogenic light (primarily the FR/R photon ratio) reflected from the SRM-Red mulch to developing parts of the sun-grown plants. The plants received incoming sunlight for photosynthesis, and the upwardly reflected morphogenic light apparently acted through phytochrome in the natural growth regulatory system within the plants to direct more photosynthate to developing fruit, which resulted in larger berries and higher yield.

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